Conflict between anthropic reasoning and observation

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Abstract

Anthropic reasoning often begins with the premise that we should expect to find ourselves typical among all intelligent observers. However, in the infinite universe predicted by inflation, there are some civilizations which have spread across their galaxies and contain huge numbers of individuals. Unless the proportion of such large civilizations is unreasonably tiny, most observers belong to them. Thus anthropic reasoning predicts that we should find ourselves in such a large civilization, while in fact we do not. There must be an important flaw in our understanding of the structure of the universe and the range of development of civilizations, or in the process of anthropic reasoning.

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I. THE PROBLEM

Where in the universe should we expect to find ourselves? What should be our circumstances? Surely we should expect to find ourselves in situations that are common for observers. That idea is formalized by Bostrom [1] as the "Self-Sampling Assumption":

> One should reason as if one were a random sample from the set of all observers in one's reference class.

Bostrom's reference class includes observers who existed in the past or will exist in the future, and I argued elsewhere [2] that even observers who might have existed should be included. But those extensions will not be necessary here. The problem will exist even if we confine ourselves to those observers who exist presently.

What is the set of presently existing observers? If we accept the theory of inflation, then evidently the universe is infinite. Generically, models of inflation are eternal, meaning that there are always places in the universe where inflation is still going on [3, 4, 5]. Thus an infinite amount of space is produced. Then, since regions of the infinite universe that are very far apart develop independently, there will be an infinite number of regions very similar to ours and an infinite number different in all possible ways [6][1]. Thus the set of presently existing observers is infinitely large and very diverse[2].

In the infinite universe, there are civilizations like ours, but there are also some which are much larger. There are stars like the sun which formed billions of years before the sun did, and thus civilizations which are billions of years older than ours. It is not impossible for such civilizations to have spread widely through the universe, and so huge civilizations exist somewhere today.

How many individuals might belong to such a civilization? We can consider the population to be the product of the number of star systems colonized and the average population of each. Estimates (e.g., [9]) for the time to colonize a galaxy completely are typically much less than a billion years, so early civilizations could easily have filled their galaxies. Our galaxy has about 10^{11} stars. We don't know what fraction have planets suitable for colonization, but some estimates (e.g., [10]) give on the order of 1%. If the 10^9 suitable planets each have the current population of the earth, about 10^{10}, then the total number of individuals will be 10^{19}.

What fraction of the civilizations currently existing are of this type? It appears that our civilization is in a short interval between coming into existence and either dying out or spreading across the galaxy. Most civilizations that exist elsewhere will have either died out already or grown large, since the time that very large civilizations endure is likely to be much longer than the time that they take to reach that stage. But we can be conservative and say that the majority, say 90%, of the currently existing civilizations are small ones.

According to these assumptions, the galaxy-wide civilizations have 10^9 times more individuals than the small ones, and are 10% as common, so all but one individual in a hundred million belongs to a large civilization. Nevertheless, we do not. Anthropic reasoning predicts that we are typical, and thus it predicts with great confidence that we belong to a

[1] In fact, there will be an infinite number identical to ours [7].

[2] It is not well defined to choose a random item from an equally weighted, countably infinite set. Instead we can consider observers in a finite but very large spherical region, and take a limit as the region becomes infinitely large [8].

large civilization. Using the estimates above, this prediction is violated in a way which has a chance probability of only 10^{-8}.

But the situation is much worse than described above. Some civilizations will have colonized beyond their own galaxies. In the extreme case, a civilization could fill a significant fraction of the future light cone of its origin. It might cover as much as 10^9 cubic megaparsecs, and so fill on the order of 10^7 large galaxies. Presumably a small fraction of the galaxy-wide civilizations have spread as widely as that, but if the fraction is more than 10^{-7}, most individuals are in those civilizations.

Similarly, some civilizations will have many more individuals at each star, because they are using the majority of the energy from their sun [11], rather than the approximately 10^{-9} that is absorbed by an earthlike planet. Again, it might be unusual, but such civilizations could have 10^9 times as many individuals at each star, and so if more than 10^{-9} of civilizations take this route, they contain most of the individuals.

It is not possible to make accurate estimates of the fraction of civilizations choosing any of these paths, but it appears that the very largest civilizations are likely to be the dominant ones, and that no more than one in a billion observers, and probably an even smaller fraction than that, are in civilizations like ours.

II. POSSIBLE SOLUTIONS

When the predictions of a theory are violated at the level of one in a billion, the theory must be rejected. So something is very wrong with the derivation above. Either anthropic ideas are not correct, or we do not properly understand the structure of the universe and the processes which enable civilizations to grow. In this section, I consider various possibilities for where the problem might lie.

A. Anthropic reasoning is wrong

One possibility is that the whole idea of anthropic reasoning is wrong and should not be used to make predictions about what we observe. But we must have some sort of anthropic procedure or we will never make any progress in science. If we reject only those theories which make our observations absolutely impossible, rather than merely unlikely, we will never get anywhere [12].

For example, consider the theory that there is a Higgs particle with a mass of $75\text{GeV}/c^2$. One might think, since the current lower bound for the mass of an undetected Higgs is $115\text{GeV}/c^2$ at the 95% confidence level [13], that such a theory has been ruled out. The argument, of course, is that if the mass were as low as $75\text{GeV}/c^2$, many Higgs particles would have been produced in accelerators and detected. But since the production process is probabilistic, there would still be some tiny chance that no such events would have occurred, and thus, somewhere in the universe, there would still be civilizations which have failed to detect the Higgs. So, if you think that we could be in any of the civilizations, rather than expecting us to be typical, then we might be in that unlucky civilization. Thus without some sort of anthropic reasoning we can never rule out any theory.

B. Anthropic reasoning should use civilizations instead of individuals

Instead of the Self-Sampling Assumption, we could use Vilenkin's Principle of Mediocrity [14], which says that we are a typical civilization among all the civilizations, rather than being typical individuals. In that case, large civilizations will not receive higher weight, and the conflict above will not occur.

Could this principle be right? It certainly is wrong if one considers a civilization to be just an arbitrary grouping of individuals. For example, we're not surprised that we are in a large galaxy rather than a dwarf galaxy, even though dwarf galaxies are more numerous, because large galaxies have most of the stars.

Of course the division into civilizations is not arbitrary. We act together as a civilization when we observe the universe and discuss the consequences of our observations. Could that fact be relevant? Consider the following analogy [2]. One day you receive a letter asking you to participate in an experiment. You know that thousands of other people will be participating, and that you will be part of a group of either 10 or 1000 people, with an equal number of groups of each kind. You should think it very likely that you will be in one of the large groups. If you find yourself in a small group, you should certainly give some thought to the idea that you didn't get selected for that role by chance, or that the experiment is not as described. You will come to the same conclusion even if you discuss your reasoning with the other people in your group after the experiment starts.

C. One should consider observers who live at any time

Instead of just those observers who exist at the present moment, one could consider all observers who have ever lived or will ever live. That idea seems quite reasonable, but it makes things worse. Aggressively expanding civilizations will generally continue to expand in the future, and so they will contain an even greater fraction of all individuals.

D. One must take account of selection bias

Perhaps we are only concerned about the problem because of when we live. Maybe members of large civilizations don't think about these problems, because they were solved by their distant forebears. Then only observers in small civilizations would think about them, and so we should not reason as if we could have been in a large one.

One can get perhaps some insight into this idea by modifying the experiment described above. Suppose that instead of each group of people being put together at once, some members are added and some removed from the groups, until the final size is reached. If you find yourself in a small group, you will still find that very surprising, even though the group could in principle become large later. If you had been added to a large group, the other members of the group might have discussed the problem already, but that does not seem to affect your conclusion.

Furthermore, if one excludes observers because they are not thinking about the sizes of civilizations, then one will bring back the problem above. Those civilizations which have already discovered the Higgs are not presently wondering what its mass is. But if we exclude members of such civilizations, then we will consider ourselves typical only among observers who have not seen the Higgs, and thus can infer nothing from our observations. To solve the

problem would require some reason to exclude observers in galaxy-wide civilizations from discussions of civilization size, while not excluding those who have discovered the Higgs from discussions of the Higgs mass. It is hard to see what that reason could be.

E. Infinitesimally few civilizations become large

It's clear that there are some large civilizations. Their existence doesn't violate the laws of physics, so they exist somewhere [7]. But if large civilizations are infrequent enough, most of the individuals will be in the small civilizations, as we are. The problem is that the frequency needs to be less than something like 10^{-9}, and that is hard to achieve. Of course there are many reasons that a civilization might remain small, including just deciding not to grow, and there are many causes which might bring it to an end [15]. It might, for example, destroy itself through nuclear war, or it might be destroyed by some natural disaster. It might wipe itself out unwittingly by some technological mistake (although the arguments of the present paper should lead it to be very careful in trying to foresee such problems). Nevertheless, it seems hard to imagine that every civilization but one in a billion suffers such fates.

One might think that the "doomsday argument" of Carter (unpublished), Leslie [15, 16], Gott [17] and Nielsen [18], in particular in the universal form discussed in [19], tells us that in fact almost no civilizations are long-lived. The doomsday argument is controversial (e.g., see [1] and references therein), but even if one accepts it, there is still a serious problem. The doomsday argument identifies the problem as being that civilizations are almost all short-lived, but doesn't tell you why they are all short-lived. Something must be wrong with our understanding of how civilizations evolve if only one in a billion can survive to colonize its galaxy.

F. The universe is not infinitely large

Of course, the theory of inflation might be wrong. Even if it is correct, it is possible to have an inflationary scenario that produces only a finite universe, although that appears to happen only in models specially designed for that purpose. If civilizations are extremely rare, there might be no large civilizations in the set of civilizations that currently exist, and so we could still be typical.

A finite universe does solve the problem, but the solution does not seem attractive. The evidence for inflation is good, and inflationary models are generically eternal. Even if not eternal, they usually produce a universe much larger than the universe we observe. Thus, the density of civilizations must be remarkably small. If 10% of civilizations are large, there must be no more than about 10 civilizations in the entire universe to avoid the existence of a large one. The problem is even worse if one includes those civilizations which have not yet arisen or grown large.

A related idea is that a true cosmological constant gives rise to a cosmological horizon, and we should not consider places which lie outside it. It's not clear why we should not count observers outside the horizon among those we could have been, but even if so the remaining universe is quite large to contain only a few civilizations.

G. Colonizing the galaxy is impossible

It appears that many stars have planets, and that interstellar colonization would be possible in the future with foreseeable technology. But it could be that some factor of which we are unaware prevents it. A radical version of this idea is that we are living in a computer simulation, and the rest of the universe does not in fact exist [20].

H. We are a "lost colony"

It's possible that we actually do belong to a large civilization, but are unaware of that fact. To include that case, one should consider the fraction of observers who *appear* to belong to small civilizations, as we do. That fraction will be infinitesimal unless a significant share of all large civilizations are made up in significant part of individuals unaware of the larger civilization. It's hard to see why large civilizations should choose to divide themselves in this way. Even if they do so, it is very inefficient, in the sense that the civilizations that have remained unified will expand more rapidly than those that are divided into isolated colonies. Thus if any reasonable fraction of the civilizations remain unified, they will still account for the great majority of individuals.

I. The idea of "individual" will be different in the future

Perhaps civilizations more advanced than ours consist of only a single individual, or only a single individual per planet, in whatever sense of individual is necessary for anthropic reasoning. In that case, even though the civilization is very widespread, the number of individuals is small. A similar idea is that individuals of those advanced civilizations are so different from us that they cannot be considered part of the same reference class, and we should not reason as though we could have been one of them.

Both those ideas seem to have a flaw, however, in that a civilization might decide to colonize its galaxy without any fundamental change in the nature of its individuals. Perhaps that is unlikely, but it doesn't seem unlikely at the level of one in a billion.

J. Many factors acting together

Perhaps the most reasonable possibility is that several of the above factors act together. For example, perhaps only 10% of civilizations survive the danger of nuclear war, of those only 10% survive the dangers of nanotechnology, of those only 10% retain their individuality, and of those only 10% decide to colonize their galaxies. If one can put together 9 factors at the 10% level, then the level of one in a billion will be reached. It seems still somewhat of a stretch (especially as the problem is likely to be worse than one in a billion) but perhaps the best explanation available.

III. CONCLUSION

A straightforward application of anthropic reasoning and reasonable assumptions about the capabilities of other civilizations predict that we should be part of a large civilization

spanning our galaxy. Although the precise confidence to put in such a prediction depends on one's assumptions, it's clearly very high. Nevertheless, we do not belong to such a civilization.

Thus something must be amiss. One possibility is that only infinitesimally few civilizations grow to large size, although it is unclear what stops them. The other is that our application of anthropic reasoning is not correct, but then what other mistakes are we making in our use of anthropic reasoning?

IV. ACKNOWLEDGMENTS

I would like to thank Luca Amendola, Nick Bostrom, Milan Ćirković, Jaume Garriga, Joshua Knobe and Alexander Vilenkin for helpful conversations. This work was supported in part by the National Science Foundation.

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